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GIS BASED ANALYSIS OF FUTURE DISTRICT HEATING POTENTIAL IN DENMARK

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ABSTRACT

The physical placement of buildings is important when determining the future potential for district heating (DH). Good locations for DH are mainly determined by having a large heat demand within a certain area combined with an access to local resources.

In Denmark, the placement of buildings and their heat demand has in recent years been assessed in a heat atlas including all buildings in Denmark. The focus in this article is to further develop a method for assessing the costs associated with supplying these buildings with DH.

The analysis takes departure in the existing DH areas in Denmark. By finding the heat production cost within these areas, and adding transmission and distribution costs, the economic feasibility of supplying areas with DH is found.

The result of the analysis is that the DH potential differs from area to area. In many areas it is economically feasible to expand DH, while in others production costs and grid losses should be reduced for DH expansions to be feasible. Including transmission and distribution costs into the calculation, gives an idea about where the boundaries for DH are. These boundaries are not static, but changes under different conditions.

INTRODUCTION

The focus on energy conservation measures is increasing both in EU policy and national legislation like the Danish. Several reports state that a 50% reduction in space heat demand is required to meet the future renewable energy targets [1, 2, 3]. In Denmark 61.3% of the 2.75 million Danish heat installations are district heating (DH) [4]. In general district heating is economically feasible when the heat generation and distribution costs are lower than the cost of the individual local heat generation [5]. In a recent Swedish study [6] the competitiveness of DH has been examined in regard to the costs associated with distribution, which is the main aspect that separates DH from individual heating.

In Heat Plan Denmark from 2008 [7], the potential for expanding DH into natural gas areas have been addressed [8]. For DH to be feasible, the local conditions are important, where the feasibility is mainly determined by having a densely populated area and access to local resources. This has led to a focus on potentials for DH in Europe [9] where the potentials are examined on the more detailed NUTS3 level, instead of the usual national level.

With the increasing focus on the importance of local conditions for heat planning and with advances in geographic information systems (GIS) and computer technology, the focus on utilizing GIS in heat planning is also increasing. For instance in larger cities like London and Paris who have developed maps of their heat demands [10, 11]. This is a very basic way to use GIS, where the heat demands are simply mapped but not used for any actual planning or analyses. In other studies the mapping of heat demands is only the first step, while the second step is to use the mapping to look into potentials for DH and CHPs. This is for instance the case for Great Britain where a map for combined heat and power development has been developed [12]. Another example is from the Swedish DH association who in 2003 made a study of connecting different DH areas [13]. A German example [14] shows a tool for creating grid based maps of heat supply in cities, which further on can be used to assess the feasibility of DH. Another example of a grid based analysis is from [15] where the heat density is used to find new areas close to an existing DH grid. A Danish example is the heat atlas developed in [16]. The heat atlas is very detailed, having heat demands on address level, but has not yet been used to examine the expansion of DH areas into areas without collective heat supply.

By using the Danish heat atlas together with cost models for DH propagation in a GIS model, the present article is a first attempt to include local conditions for DH in a national analysis for Denmark.

SCOPE OF THE STUDY

The main focus of the article is defined by the following research questions:

- How can a GIS model be constructed to include local conditions for district heating?
- Where is it under current conditions feasible to supply buildings with district heating?
- Where is district heating feasible if space heat demands are reduced?

The study is delimited to focus on socio-economic costs for DH propagation. Socio-economic costs exclude costs that are based on political agreements like taxes, subsidies or local tariff structures. The reason for using socio-economic costs is that large infrastructure projects, like DH, needs to be based on long-term planning that ensures that the projects are beneficial for society in a longer perspective. This is also why the Danish heat supply law [17] states that

DH companies have to carry out a socio-economic calculation for all expansion plans. Therefore, neither business- nor private economic considerations have been taken into account in this article. Also the focus is so far only on current costs and technologies, not taking e.g. increasing fuel prices into consideration. All the costs are from national documents, meaning that local variations are not considered.

METHODS AND DATA COLLECITON

The heat atlas is based on data from the Danish Buildings Register (BBR) and a methodology from the Danish Building Research Institute (SBi) for calculating the heat demand of buildings based on age, type and usage, the latter is described in detail in [18].

An essential part, when examining DH propagation, is not only to focus on each individual building, but to examine areas of buildings which are geographically close to each other, so that the benefits of heat dense areas will be considered. Since the information from the heat atlas is on the individual address level, the information needs to be summarized in larger areas. This can be done in several ways, but to represent the physical reality best, built up areas from the Danish Common Public Geodatabase (FOT) [19] is used. In FOT the built up areas are mapped as four categories: dense city, multi-storey buildings, low buildings and industry. By using these areas, the heat demands and associated areas are close to buildings plots, not including park areas, roads etc. Additionally data from the Danish Address and Road Database (DAV) is used.

The source for information on all Danish DH areas is a data extract from the Danish Energy Agency's energy producer count from 2009 [20], which includes information on all heat and electricity producers in Denmark.

COST MODELS FOR DISTRICT HEATING

The following subsections describe the cost models for DH used in a GIS model to examine the DH potential in Denmark. The costs are divided into production costs, transmission costs and distribution costs. Altogether these costs define the total cost of supplying an area with DH. All costs are given as long-run marginal costs, which includes investment costs, operation costs and fuel costs, but also enables a comparison between technologies with different lifespans.

Production cost

The first model assesses the production costs of existing DH systems in Denmark. The cost related to production within DH (excluding transmission and distribution costs) mainly consists of investment costs in production capacity, fuel costs and operation and maintenance costs. In Denmark all electricity and heat producers report their energy production and fuel consumption to the Danish Energy Agency in an annual producers count [20]. By joining the information from the producers count with a map of DH areas, it is possible to assess the local costs. A national map of DH areas has not been maintained around 2003, therefore the areas used in this study are based on information from [21]. In the present study the costs used are based on two documents: the preconditions for socio-economic costs [22] and the energy technology data sheet [23], both made by the Danish Energy Agency. Using these two sources for all production costs standardizes the costs and excludes local differences in costs. The negative aspect of this choice is that in some places the costs will differ so much from the actual costs that the calculations would not give the same results as doing more specific analyses. One reason for these differences is that the costs of local resources often depend on specific agreements among the suppliers and the DH companies, which naturally gives variations in costs. Finding local variations in costs would certainly have been more precise, but would take a long time to carry out. On the other hand the positive sides of using these two sources are that the calculations are more transparent and give certain coherence in the calculations. Also they make it possible to include a variety of fuels and technologies in the calculations, without spending time on getting local data. The costs in the model are calculated separately for fuel costs and cost related to investments in production capacity and operation and maintenance (O&M).

Fuel costs

The fuel costs for each DH area are found by multiplying the annual fuel consumption for each production unit with the fuel costs. Afterwards the costs are allocated between produced heat and electricity. In general allocation methods are subjective and therefore two methods are used in the model, to give an insight into the importance of this allocation, both are based on [24] from the Danish TSO. The first method used for the allocation is the called the energy content method, and uses the formula:

$$\frac{\mathrm{Q}_{production}}{\mathrm{P}_{production}+\mathrm{Q}_{production}} \cdot \mathrm{Fuel}_{consumption} \quad (1)$$

The second allocation method is the energy quality method, see formula 2. This is a modified version of the energy content method, where based on experience the allocation model uses 1 kWh heat to substitute 0.15 kWh electricity.

$$\frac{\mathrm{Q}_{production} \cdot 0.15}{\mathrm{P}_{production}+(\mathrm{Q}_{production} \cdot 0.15)} \cdot \mathrm{Fuel}_{consumption} \quad (2)$$

The energy quality method allocates a larger share of the costs to the electricity side than the energy content method, which means that this method is more positive towards DH. After the allocation the total annual fuel cost assigned to the heat side is summarized for each DH area. Finally the total annual fuel cost for each DH area is divided by the total annual heat delivery giving a EUR/GJ price for each area. By using both produced and delivered heat in the fuel cost calculation, the grid loss is indirectly included in the fuel cost. The following section describes the second part of the heat production cost model, which is the cost of annual investments and O&M.

Investment and O&M cost

In Denmark a variety of different technologies are used for DH production. All of these technologies have different costs associated with investments and operation of the plants. Therefore, it is necessary to assess these costs and as mentioned above, the Danish Energy Agency produces a technology catalogue approximately every year, where information about different present and future technologies is collected. This information includes a description of the technology, technical data about efficiencies and expected lifetime of a plant, but it also includes information on the economics, where investment costs and O&M costs are the main categories.

All in all 32 different categories for technologies are used to assess the cost of annual investments in capacity and operation and maintenance. Since the process of assigning these categories has to be carried out manually, it is chosen to focus only on the main producers within each area. Therefore, the backup units and peak-load units are excluded from the cost calculation. In total there are 1710 production units included in the producer count, after excluding presumed peak- load units with less than 438 full-load hours per year this is down to 842 units. For each of these 842 units one of the 32 categories has been assigned manually by looking at the primary fuel use, the name of the production unit and the capacity of the unit. This makes it possible to assign annual costs for each of the plants according to the prices from the Danish Energy Agency. The benefit of this procedure is that the costs are transparent and comparable, and can easily be updated in future versions of the model, on the other hand the downside is again that the local variations are not included.

In general the costs can be split into two categories, the fixed costs and the variable costs. The fixed costs consist of annual investment costs and O&M costs which are not determined by the plant operation of the plant. The variable costs on the other hand are mainly O&M costs which are associated with the utilization of the plant. Therefore, the fixed costs are determined by the production capacity of the plant and the variable costs are determined by the annual energy production. To arrive at a marginal production cost, it is necessary to find the annual fixed costs by using equation 3. The calculation is carried out using the lifetime of each technology and a discount rate of 6%. The lifetimes vary between 10 and 40 years, depending on the technology.

$$a \cdot I = I \cdot \frac{i}{1-(1+i)^{-n}} \tag{3}$$

Since many plants produce both heat and electricity, the allocation models presented in the previous section are both used to assign a share of the total annual cost to the heat.

Total heat production cost

An overview of the resulting heat costs is shown in Figure 1 which shows the total long-run marginal production costs including fixed costs, variable costs and fuel costs all based on the year 2009.

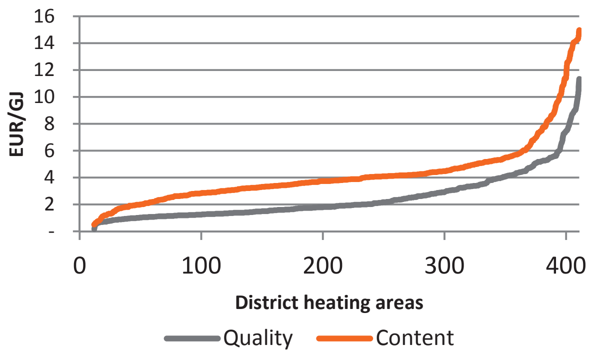

Figure 1: Long-run marginal cost for heat production in DH areas

As seen in Figure 1, the choice of allocation method is important when assigning costs to DH. If only the energy quality method is used, the costs associated with heat production will be very low, while on the other hand using the energy content method the costs will be higher.

Transmission cost

To avoid placing transmission pipes in restricted areas, the pipes follow the road network in the GIS model. In reality transmission pipes would not always follow the roads, so in some cases the length found in the model is a conservative estimate. By using a network analyst tool in GIS, the transmission pipe length to the closest DH area for 150,156 built up areas outside DH is found. To be able to carry out the analysis all the areas have been defined as points by using a polygon to point tool. After finding the length of the pipes the needed capacity of the pipes are found. This is done by dividing the annual energy demand in the area, given in MWh per year, by 3000 full-load hours, giving the need for capacity in MW. To find the cost of establishing the transmission line, a cost in EUR per meter is used, see Table 1. The calculations of capacities are based on a temperature difference of 55°C and the water flow in the table.

Table 1: Total cost of transmission pipes including projecting, field work, pipe work, materials and digging, based on [25] graph C.

Dimension DN	Water flow m/s	Capacity MW	Cost EUR/m
32	0.9	0.2	195
40	1.0	0.3	206
50	1.2	0.6	220
65	1.4	1.2	240
80	1.6	1.9	261
100	1.8	3.6	288
125	2.0	6.1	323
150	2.2	9.8	357
200	2.5	20	426
300	2.7	45	564
400	2.8	75	701
500	2.9	125	839
600	3.0	190	976

To find the total cost of each transmission line, the length and cost per meter is multiplied for all transmission lines. Finally, the transmission cost is annualized by using equation 3 with a lifetime of 30 years and discount rate 6%. Afterwards the total cost is divided by the heat demand in each area to give the annual EUR/GJ cost for transmission to the area.

Distribution cost

While the previous section determined the cost of building transmission lines between areas, this section assesses the heat distribution costs within each area. According to [6] the distribution cost consists of four categories:

- Distribution capital cost
- Heat loss cost
- Pressure loss cost
- Service and maintenance cost

The main cost category is the distribution capital cost which will be the focus in this section. The heat loss costs are included in the heat production cost model described in the production cost section. The distribution capital cost is the investment cost of constructing the DH network. In [6] the expression for distribution capital cost is reformulated in the following way:

$$C_d = \frac{a \cdot I}{\left(\frac{Q_s}{L}\right)} = \frac{a \cdot (C_1 + C_2 \cdot d_a)}{p \cdot \alpha \cdot q \cdot w} \quad (4)$$

C_d is the annual distribution capital cost, which consist of the annual investment divided with the linear heat density. The linear heat density has historically been used to measure the effectiveness of existing DH systems based on empirical evidence. The linear heat density is expressed as Qs/L or the annual sold heat divided with the total trench length of DH system. In equation 4 the linear heat density is reformulated to consist of four parameters where p is the capita/m^2 land area, a is the m^2/capita building area, q is the annual demand in GJ/m^2 building area and w is the effective width. The first two parameters are known as the plot ratio. When the plot ratio is known, the expression can be reduced to equation 5, where e is the plot ratio.

$$C_d = \frac{a \cdot (C_1 + C_2 \cdot d_a)}{e \cdot q \cdot w} \quad (5)$$

The effective width is a measurement for pipes required per land area. As the concept is used in [6] the data is based on a database including overall information about urban areas, which means that it is an aggregated model of areas. By aggregating the information from the heat atlas to areas from FOT, a more detailed model of distribution cost can be constructed.

The heat atlas and the FOT data are the only inputs for the distribution cost model. The main parameters used are the heat demand and the building area. These are used to find the three parameters used for calculating the linear heat density. The first is the specific heat demand, which is the heat demand divided with the building area, which gives the GJ/m2. The second is the plot ratio, which is the building area divided by land area. The third is the effective width which uses the plot ratio as the input parameter. In previous Swedish studies [6] and [26] the effective width has been examined, but since the present model is used for Danish conditions, data from the DH company in Aarhus has been collected, see Figure 2.

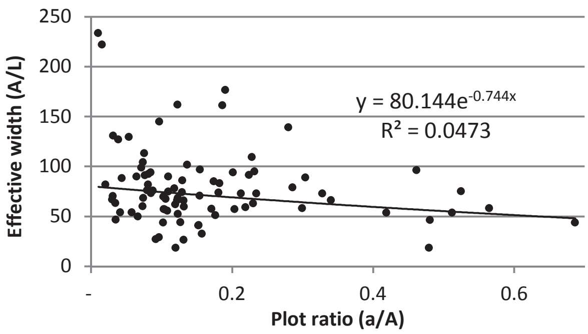

Figure 2: Effective width based on 88 DH areas in Aarhus

Based on Figure 2 the effective width can be found by using the formula:

$$w = 80.144 \cdot e^{-0.744 \cdot plot\ ratio} \quad (6)$$

Formula 6 is close to the correlation in the before mentioned Swedish studies. However, it must be underlined that the correlation between the plot ratio and effective width is very weak, so it should only be seen as a weak tendency towards a lower effective width with an increasing plot ratio. The formula is only applicable for plot ratios below 0.7, so in the model for areas with a plot ratio above 0.7 the effective width has been assumed to be 50 meters.

ANALYSIS OF DISTRICT HEATING POTENTIAL

By using the GIS model, developed in the previous section, the potential for expanding DH is examined. In general this is done by finding the cost of supplying all areas with DH that are not supplied with DH today. Instead of comparing the cost of the DH supply to the existing heat supply, it is compared to the least expensive individual supply option, which in the case of Denmark is a ground source heat pump. This is both to simplify the calculations and to secure that DH is not chosen in areas where heat pumps might be a more feasible solution. Since there are uncertainties associated with the cost calculation for DH, the heat pump cost is reduced with 10% to exclude areas that are too close to the individual supply cost. The heat pump costs consist of investment costs, O&M costs and electricity consumption cost. The heat pumps are assumed to have an average COP of 3.29, a lifetime of 20 years and the electricity price is set to 65 EUR/MWh [23, 22]. This result in a long-run marginal cost of 22.65 EUR/GJ, reduced by 10% the cost is 20.39 EUR/GJ, which is used as the limit for when DH is considered feasible.

The analysis consists of two different scenarios:

1. Current heat consumption in buildings
2. Reduced heat consumption in buildings

Both of these scenarios are based on the current supply in DH areas and the current costs of fuels and technologies. The goal with the second scenario is to show the feasibly of DH if DH areas do not change. The heat consumption is in average reduced by 75% in the second scenario, which is technically possible according to [18].

RESULTS

Since the model operates on a very detailed level it is not possible to show the map output for the whole of Denmark, even though the analysis is carried out for all DH areas in Denmark. However, Figure 3 shows an example of the output of the model, where the existing DH area is depicted with grey and the built area outside DH is depicted with red. By comparing the cost of supplying each of the red areas with DH to the cost of supplying them with individual heat pumps the blue areas are found. The blue areas show the areas where DH is feasible compared to heat pumps. There are different potentials depending on the cost allocation method used, where the light blue areas are the energy content method, which allocates more of the investment costs to the heat side, while the dark blue areas are the energy quality method which allocates most of the costs to the electricity side. This also means that all the light blue areas are also included as the potential in the energy quality method. There are some general tendencies to draw from the example, first of all that dense areas close to the DH area are mostly feasible and secondly that the areas need to be

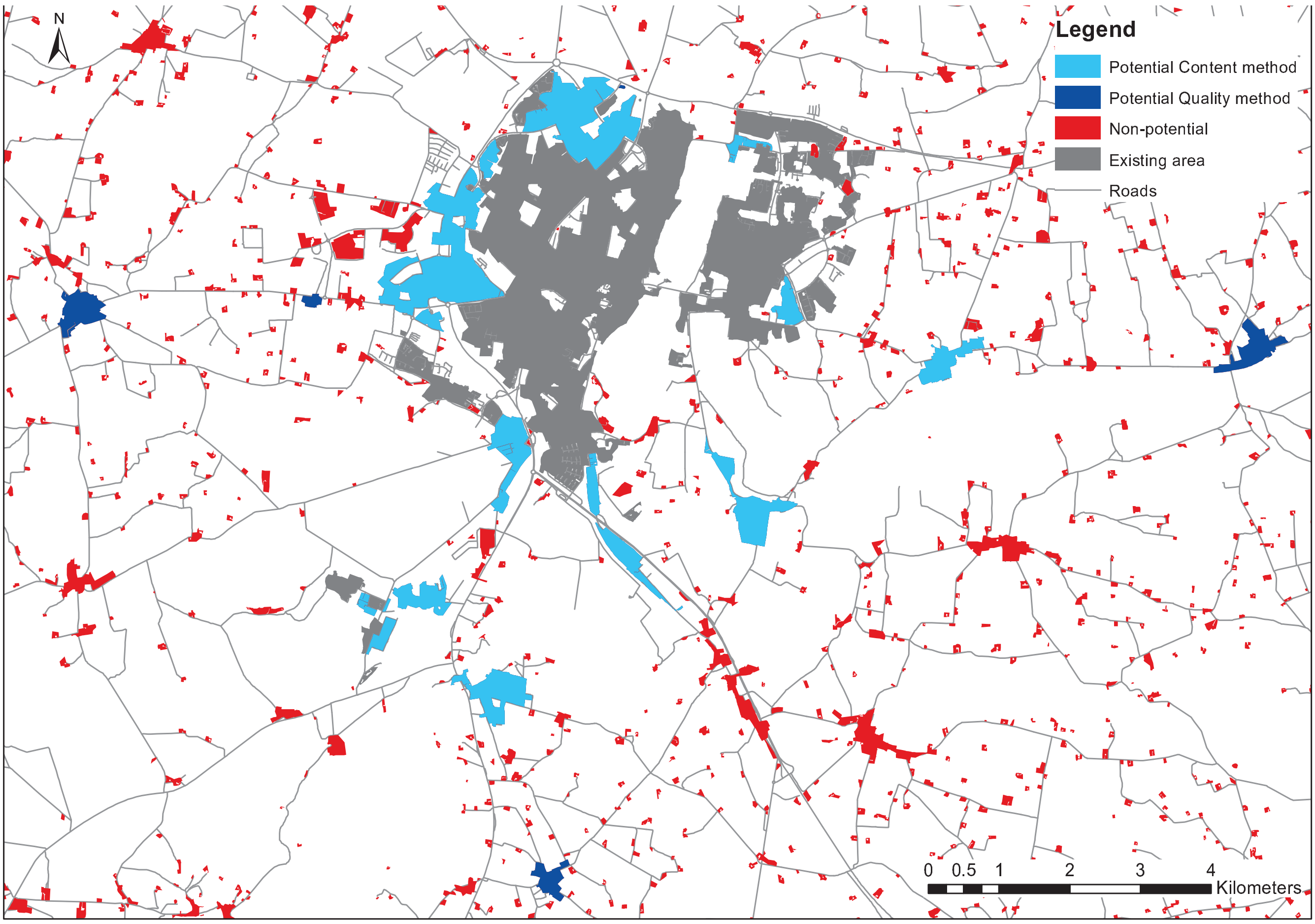

Figure 3: Example of output from GIS-model

larger when further away from the DH area. This supports the basic assumptions of the economics of DH propagation. The heat demands within each area cannot be seen from the map, but in general larger areas have larger demands.

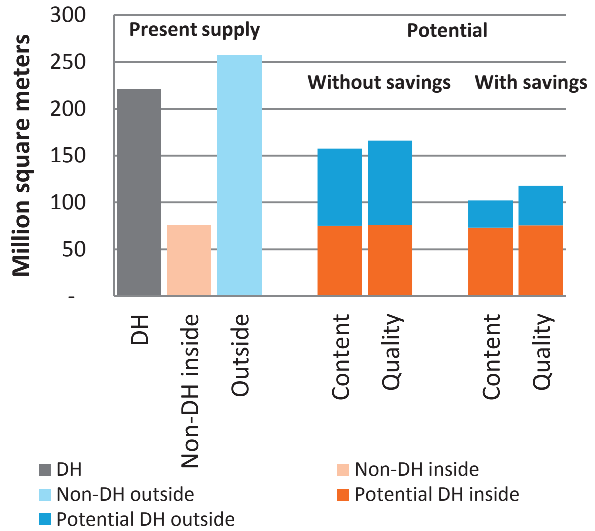

Figure 4: Total potential given in million m² built area

In Figure 4 the overall result of the model is shown. It shows that without savings there is quite a large possibility to expand DH in Denmark. Depending on the allocation method the potential inside is around 70 million m² of buildings, and the potential area outside DH areas is around 80 million m². In the scenario with heat savings the potential decreases, mostly in areas outside DH.

Examining these potentials individually for each DH area, shows that there are large variations between areas, see Figure 5.

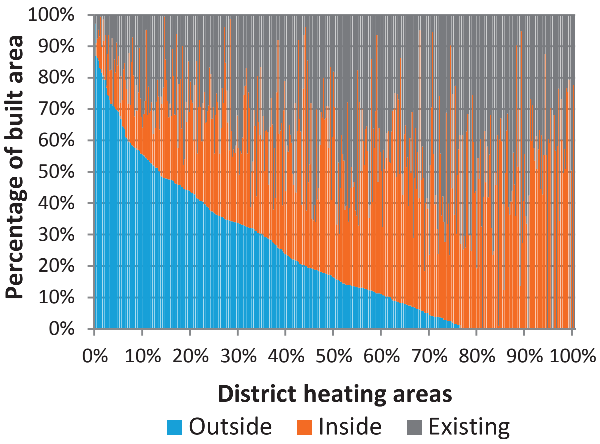

Figure 5: Building area distribution for each DH area (Energy Quality Method)

In 15% of the areas more than half of the built area is outside the existing areas, while in 22% of the areas the DH is not expanded beyond its current area. In most DH areas it is feasible to connect buildings inside.

These results reflect that the difference in the geographic distribution of the heat demands and the difference in costs are important in relation to the potential.

Figure 6 shows a graph of the heat demands of all areas outside DH sorted by the total cost from lowest to highest. As the long-run marginal cost of individual ground source heat pumps are assumed to be 22.65 EUR/GJ, the figure show that around 50% of the heat demand outside DH is more costly to supply than the individual alternative.

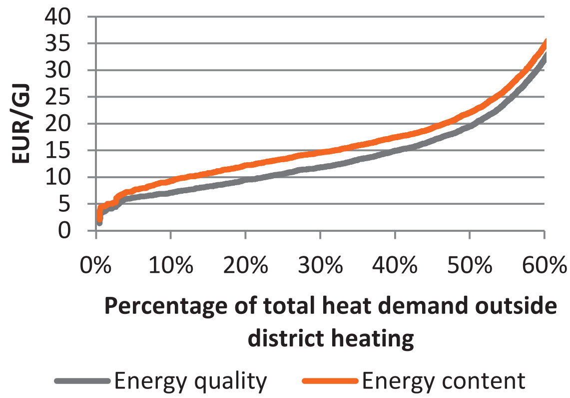

Figure 6: Total costs for potentials outside DH

In Figure 7 the costs are divided between production, distribution and transmission, for the potential areas outside DH and based on the current heat consumption. In general the transmission costs are in all cost categories, with most areas below 4 EUR/GJ. The main part of distribution costs are in the range 2-8 EUR/GJ and the production costs are mainly below 8 EUR/GJ.

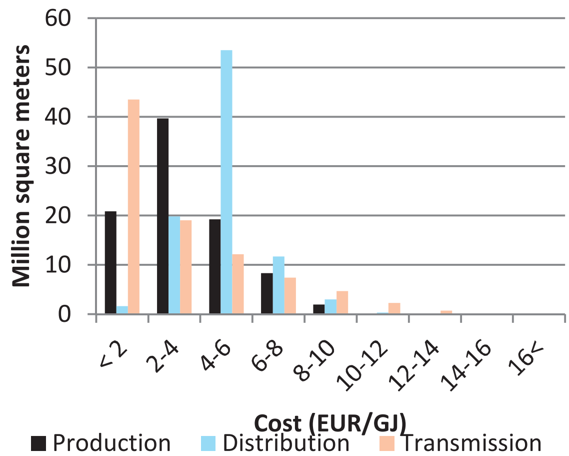

Figure 7: Potential outside (energy quality method and no heat savings)

DISCUSSION

The main focus of the article is to develop a method for calculating the DH potential by including all the major cost categories of supplying buildings with DH. In its current version the model can only be used as a screening tool and not as a tool for local planning. Due to the data inputs the results cannot be extracted on e.g. municipal level and used in concrete decisions. However, with local data inputs the methodology used in the model could be used for these purposes.

The inputs for the model are mainly heat demands, building areas and costs regarding the heat supply. The building related inputs are based on the BBR register, which includes several errors [27]. It is however, the most complete data on buildings for Denmark. The inputs regarding costs are based on a generalization of costs, meaning that there are no local variations in fuel costs or production capacity costs, or the other variable costs. This makes the costs transparent but also gives uncertainties compared to the actual costs in each area. The existing maps of DH areas in Denmark are outdated due to a lack of updating. Therefore, the geographic boundaries used in this study are based on combined information from several sources. This gives uncertainties in the model, but is necessary to be able to analyse the potential. The mapping of DH areas should have high priority in the future, since it is essential for estimating the propagation costs.

In Denmark the Danish Energy Regulatory Authority registers consumer costs in all DH areas, these costs are not very transparent, but could be used if the model should be used for private economic purposes. However, a private economic analysis has a different purpose than the present study and would most likely not include the benefits of supplying heat dense areas, when the costs are not allocated between production, transmission and distribution. An important cost that the model does not include is the cost of maintaining the existing DH grid. It could be added to the heat production cost in an area, but would require more detailed data on each DH area. Also the costs for increasing the production capacity in areas where the existing production units cannot cover the demand associated with an expansion, is not included. This means that in areas where the potential is much larger than the existing supply capacity, the cost could be higher than in areas where the expansion can be covered by the existing capacity. This should be included in further studies, since it is an essential part of calculating the feasibility of expanding DH areas.

The results of the analysis show that even though a large share of the Danish buildings stock is supplied by DH, there is a potential to expand even further. In the scenarios based on the current heat consumption, it is feasible to expand the DH areas from 40% to 68-70% of the total heated area. In the scenarios with a reduced heat demand, the feasible share drops to 58-61%. This indicates that unless DH areas improve, the potential feasible share for DH will be reduced with the improvements in the buildings stock. There are many options for DH areas to adjust to this new situation. One option is to change from expensive fossil fuels to less expensive renewable energy sources. This is a development that can be seen in many areas already, where more and more areas are building solar thermal collectors to reduce the natural gas production. Another way to adjust to the new situation would be to improve the efficiency in the system by reducing grid losses and lowering supply temperatures.

In the scenarios different allocation methods have been used for allocating the costs between heat and electricity production. These methods influence the results and therefore the choice of method should be considered carefully in areas where the costs are close to the individual supply cost. If more detailed information about the production units is accessible, it should be considered to use an allocation method based on the market prices of electricity.

What separates this study from many previous studies is the choice to separate DH costs into three categories. From the analysis it is clear, that this is an important distinction to make, so that areas with high heat densities and low distribution costs, and areas with a short distance to supply areas and low transmission costs, are more feasible than other areas. If the focus is only on the existing heat price, these benefits are not included, and it is very likely that DH propagation will not be considered even though it is socio-economically feasible.

CONCLUSION

This article examines how a heat atlas of Denmark can be used in combination with a GIS model of DH costs, to assess the potential for DH propagation. The cost models for DH are designed to include local variations and are based on long-run marginal costs. By separating the costs into three main categories; heat production, heat transmission and heat distribution, the total cost of supplying areas that are not connected to DH is found. This gives a model where local variations are included, meaning that the expansion potential differs from area to area depending on production costs and the geographic placement of the heat demands. In the model the current supply is used as the basis for finding the potentials.

The DH potential is examined in four scenarios, two based on the current heat demands and two on a reduced heat demand. In the present Danish system DH covers 40% of the total built area. The scenarios with current demands show a potential for increasing this area by 13-14% inside and additionally 15-16% outside, depending on the allocation method used. So in the most positive scenario, it gives a DH potential of 70% of the total built up area in Denmark. In the scenarios with decreased demands the potential is between 13-14% inside and 5-8% outside, giving a potential between 58-61%. This shows several things, first of all that there is an expansion potential in all scenarios, secondly that the allocation method is important, and finally that if DH areas wants to keep the heat market share they should improve the system by changing fuels and minimizing grid losses.

The results also show that including local variations are necessary to give the full picture of DH costs, it is not enough to base heat supply decisions in heat dense areas on separate buildings. This is mainly due to the fact that the costs related to heat distribution is reduced in areas with a high heat density. Therefore, in general heat supply decisions should be based on the spatial placement of the heat demands and the characteristics of the local DH area.

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